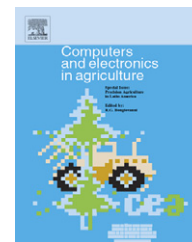


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# Assessment of nitrogen losses to the environment with a Nitrogen Trading Tool (NTT)

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## ARTICLE INFO

### Article history:

Received 27 September 2007

Received in revised form

4 January 2008

Accepted 26 February 2008

### Keywords:

Nitrate leaching

Nitrogen credits

Nitrogen Trading Tool

NLEAP

NTT

N<sub>2</sub>O

Global Warming Potential

Carbon Sequestration Equivalents

## ABSTRACT

Nitrogen (N) losses from agriculture often contribute to reduced air, groundwater, and surface water quality. The minimization of these N losses is desirable from an environmental standpoint, and a recent interest in discounted reductions of agricultural N losses that might apply to a project downstream from an agricultural area has resulted in the concept of *N credits and associated N trading*. To help quantify management-induced reductions in N losses at the farm field level (essential components of a Nitrogen Trading Tool), we defined a Nitrogen Trading Tool difference in reactive N losses (NTT-DNL<sub>reac</sub>) as the comparison between a baseline and new management scenarios. We used a newly released Windows XP version of the Nitrogen Losses and Environmental Assessment Package (NLEAP) simulation model with Geographic Information System (GIS) capabilities (NLEAP-GIS) to assess no-till systems from a humid North Atlantic US site, manure management from a Midwestern US site, and irrigated cropland from an arid Western US site. The new NTT-DNL<sub>reac</sub> can be used to identify the best scenario that shows the greatest potential to maximize field-level savings in reactive N for environmental conservation and potential N credits to trade. A positive NTT-DNL<sub>reac</sub> means that the new N management practice increases the savings in reactive N with potential to trade these savings as N credits. A negative number means that there is no savings in reactive N and no N available to trade. The new NLEAP-GIS can be used to quickly identify the best scenario that shows the greatest potential to maximize field-level savings in reactive N for environmental conservation and earning N credits for trade.

Published by Elsevier B.V.

## 1. Introduction

There is potential to apply environmental credits to fiscally account for reductions in non-point sources of nitrogen (N) (Greenhalch and Sauer, 2003; Ribaud et al., 2005). Glebe (2006) reported that agri-environmental payments may legiti-

mately be used as incentive to reduce environmental impacts of farming practices even if these practices also have a positive production effect. Nutrient management practices that reduce the transport of N into water bodies may contribute to the earning of N credits (Hey, 2002; Hey et al., 2005).

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0168-1699/\$ – see front matter. Published by Elsevier B.V.

doi:10.1016/j.compag.2008.02.009

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Natural Resources Conservation Service

# Nitrogen Trading Tool

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## Management Information

On this page, identify the cropland area and enter the information needed to compare the nitrogen loss potential between a baseline management system and an alternative conservation management system.

Click [HERE](#) to read more about entering Management Information.

Enter your cropland area information below. After you have entered all of the required (\*-Required) information, click the **NEXT** button to continue.

### Enter your Management information.

State: **Virginia** County: **Fairfax**

Name ?

Description ?

Soil area\* ? **Fairfax County**

Soil name\* ? **(select one)**

Area(acres)\* ? **0**

Baseline ? D	Alternative ? D
Cropping system* ? <b>(select one)</b>	<b>(select one)</b>
Irrigation* ? <input type="text"/>	<input type="text"/>
Nitrogen input* ? <input type="text"/>	<input type="text"/>
Tillage* ? <input type="text"/>	<input type="text"/>
Tile drainage ? <input type="text"/>	<input type="text"/>

#### Baseline Activities ?

☐ Contour Buffer Strip

☐ Filter Strip

☐ Riparian Forest Buffer

#### Alternative Activities ?

☐ Contour Buffer Strip

☐ Filter Strip

☐ Riparian Forest Buffer

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Fig. 1 – Web-based Nitrogen Trading Tool user interface (from Gross et al., 2008).

Since the quantification of N losses from agricultural fields is difficult (Delgado, 2002), computer models present an alternative to quantify and assess the effects of best management practices on reduction of N losses to the environment (Delgado, 2001; Shaffer and Delgado, 2001). The Natural Resources Conservation Service (NRCS), in cooperation with the Agriculture Research Service Soil Plant Nutrient Research Unit (ARS-SPNR), developed a prototype web-based Nitrogen Trading Tool (NTT) (Gross et al., 2008; Fig. 1). The web-based prototype allows farmers to quickly determine how many potential N credits their farming operations can generate.

Gross et al. (2008) reported that there is no current alternative tool with the web-based NTT's level of rigor. The web-based NTT allows producers to calculate potential N credits as a function of implementing conservation measures. Environmental aggregators, brokers, and water quality traders have all responded positively to the new web-based NTT prototype (Gross et al., 2008; EPA-WQTN, 2007). These NRCS efforts to develop an NTT are part of the cooperation between the USDA-NRCS and the EPA Office of Water to participate in potential water quality trading programs (EPA-WQTN, 2007). This paper presents the new NTT concept of using personal computer-based modeling software and or Web-based to quantify reduction in N losses (Fig. 2).

### 1.1. Nitrogen Trading Tool (NTT)

The model used for the web-based NTT prototype is the Nitrogen Leaching and Environmental Losses Package (NLEAP) (Shaffer et al., in press). The model connects national

databases with information on weather, soils, and cropping systems events (Fig. 3). The NTT prototype has been set up both as a web-based interface (Gross et al., 2008; Fig. 1) and as stand alone software (Delgado and Shaffer, in press; Fig. 2). The sensitivity of this model to simulate N management across different agroecosystems, practices, soils, and weather combinations has been widely tested (Fig. 4).

NLEAP has been compared by Khakural and Robert (1993) and Beckie et al. (1994) to other available models. They conducted independent NLEAP evaluations to test and compare the sensitivity of NLEAP to several of the other available N models. Additionally, NLEAP has been widely tested across several sites in the USA and internationally by independent user groups (Fig. 4).

Khakural and Robert (1993) and Beckie et al. (1994) reported that NLEAP simulations of residual soil  $\text{NO}_3\text{-N}$  and soil water content in the root zone were as accurate as the simulations conducted by other computer models such as the Erosion/Productivity Impact Calculator (EPIC) (Williams et al., 1983, 1984), the Crop Estimation through Resource and Environment Synthesis (CERES) model (Ritchie et al., 1985), Nitrogen-Tillage-Residue Management (NTRM) (Shaffer and Larson, 1987), and LEACHM-N (Wagenet and Hutson, 1989).

The NLEAP model has been used intensively across the USA to simulate N management scenarios. Walthall et al. (1996) simulated N management for cotton (*Gossypium* spp.) grown in Louisiana while Kaap et al. (1995) simulated best N management practices for alfalfa (*Medicago sativa* L.), corn (*Zea mays* L.), and snap bean (*Phaseolus vulgaris* L.) grown in Wisconsin. In Colorado, assessments of the effectiveness of

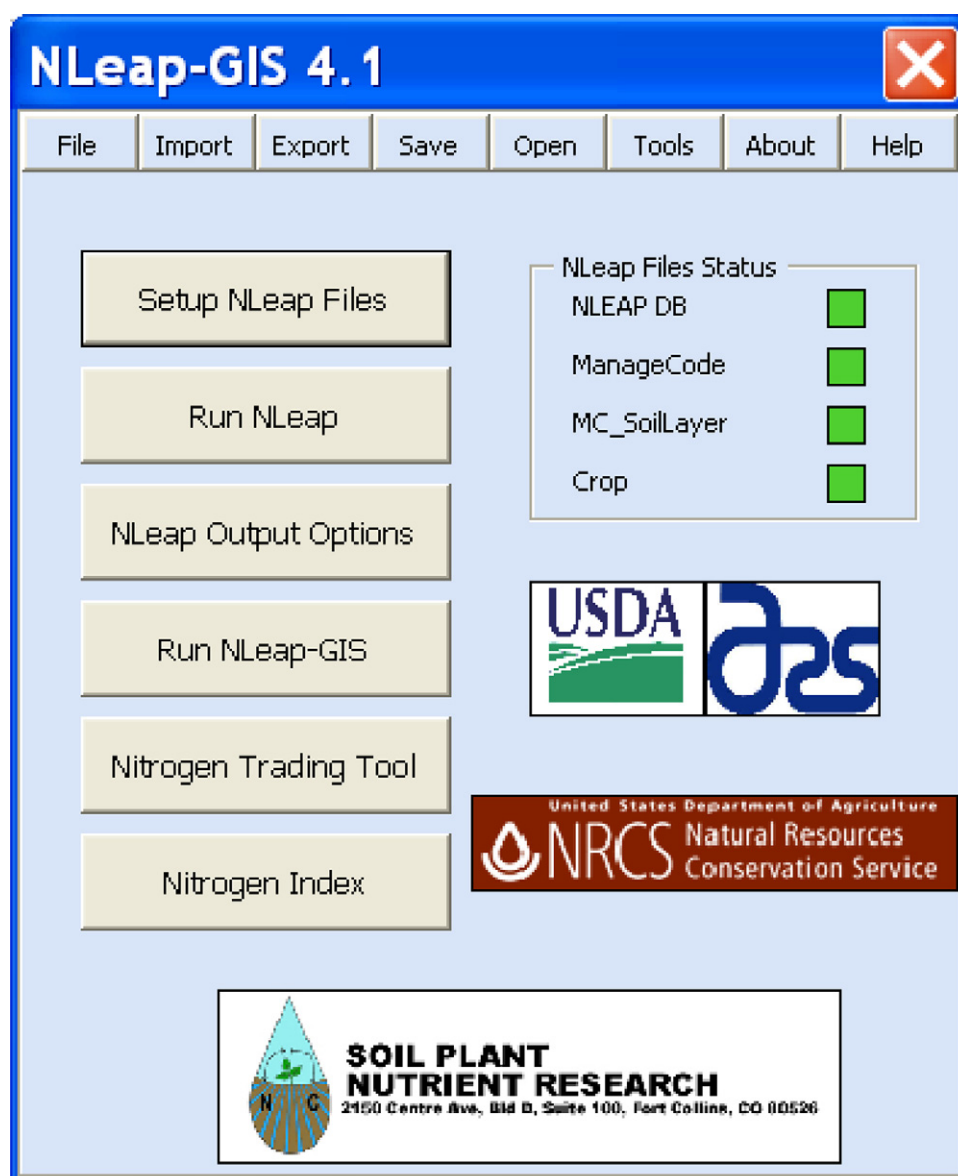


Fig. 2 – A stand alone version of the NLEAP Nitrogen Trading Tool interface.

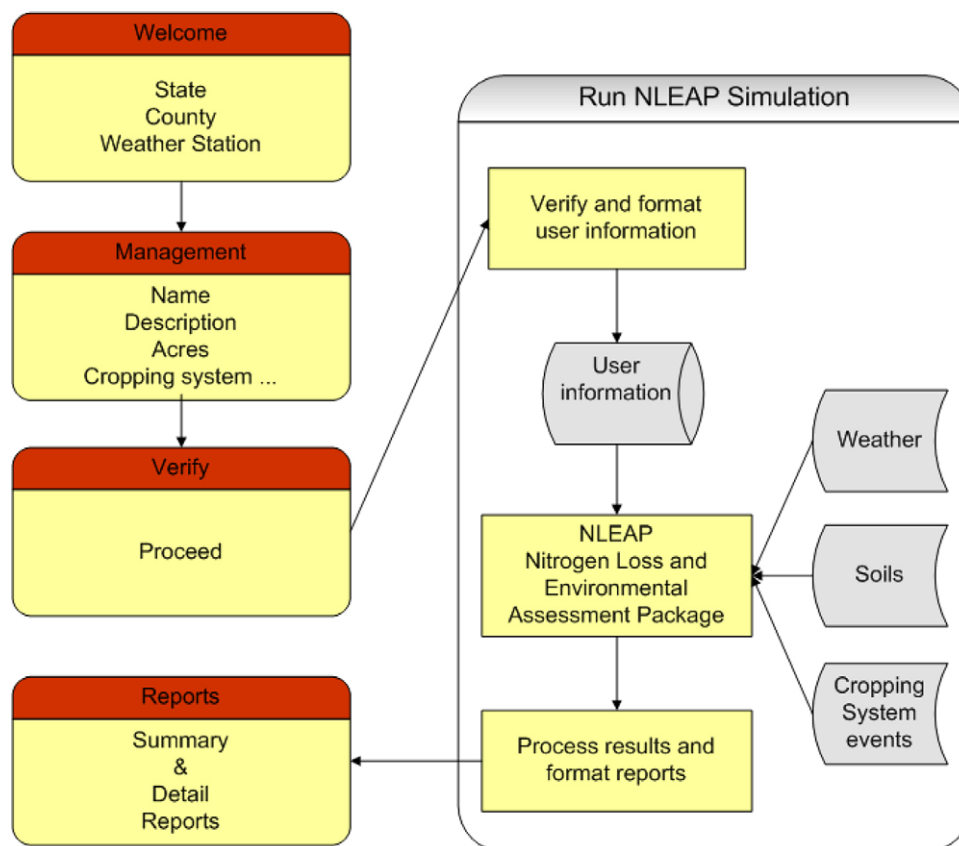
best management practices in reducing N losses from crops of potatoes (*Solanum tuberosum* L.), lettuce (*Lactuca sativa* L.), wheat (*Triticum aestivum* L.), winter cover rye (*Secale cereale subsp.*), and barley (*Hordeum vulgare* L.) were conducted by Delgado et al. (2001a,b).

NLEAP has also been tested extensively at the international level. Stoichev et al. (2001) used NLEAP to assess the effects of N management practices for sunflower (*Helianthus pumilus*), winter wheat, corn, and vegetables grown in Bulgaria. Rimski-Korsakov et al. (2004) used NLEAP to evaluate the effects of best management practices for corn grown in agricultural soils of the Pampas Region, Argentina. De Paz (1999) used NLEAP to evaluate irrigated systems with vegetable crops such as potato, cauliflower (*Brassica oleracea* var. botrytis), and onion (*Allium cepa* L.) grown in a Mediterranean region of Spain. Ersahin (2001) used the NLEAP model to assess N losses from wheat grown in Turkey.

## 1.2. NTT definitions

The procedure to assess change in N losses to the environment is simply a mathematical difference between a baseline and the new N management scenarios (N losses in base scenario–N losses in new scenario). We propose that a uniform conceptual framework be used to assess the potential benefits of trade-driven management practices by applying simulation modeling and then comparing changes in N losses that can be translated into N credits.

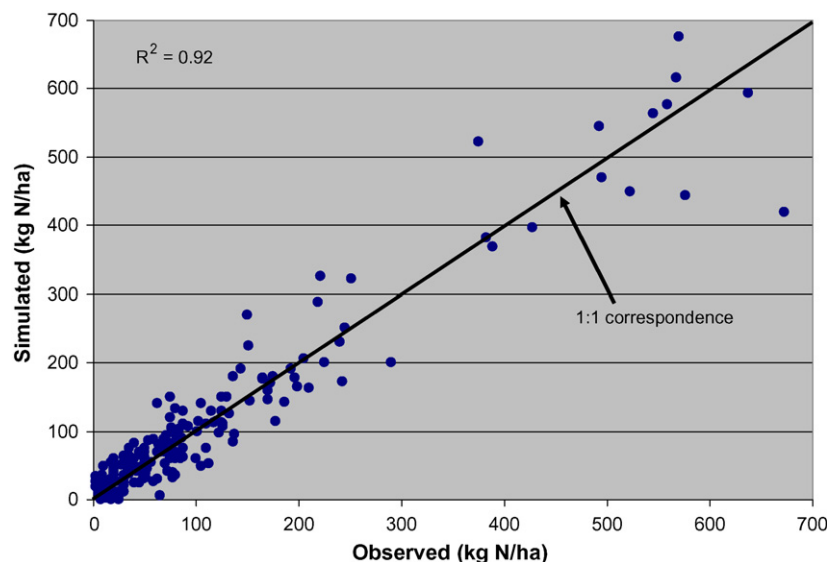
We cannot simultaneously include reductions in N inputs and N losses, since this would be double accounting. Depending on local and regional conditions, proposed management changes may or may not have immediate effects on N losses, and the magnitude of these effects is likely to change over time. To avoid accounting for N inputs twice, we need to understand and assess the N inputs, processes, and N losses with an



**Fig. 3 – The web-based Nitrogen Trading Tool couples the scientifically rigorous nitrogen loss and Environmental Assessment Package (NLEAP) model with a user-friendly web interface to allow the producer to easily calculate potential nitrogen credits (from Gross et al., 2008).**

N balance approach within the N cycle (Delgado, 2002; Follett and Delgado, 2002). A modeling approach based on long-term simulations is recommended to evaluate the effects of management scenarios accounting for the effects of N inputs, crop

rotations, and other management options on N losses from the field over a long-evaluation period. The bottom line on determination of N credits should be what effect can be expected at the target project over the lifetime of the project.



**Fig. 4 – As an example, the combined results for 200 site-years of validation testing of NLEAP under irrigated, and non-irrigated agriculture in the USA, Argentina and China sites.**

Quantification of N losses to the environment is difficult because N is very mobile and dynamic with several loss pathways (Delgado, 2002). Therefore, mathematical difference between the base scenario and the new N management scenario is assessed by adding individual pathway NTT-DNL<sub>reac</sub> values. Since denitrification (N<sub>2</sub>-N) losses could be beneficial to the environment (Mosier et al., 2002; Hunter, 2001; Hey, 2002; Hey et al., 2005), we calculated the NTT mathematical difference in reactive N losses (NTT-DNL<sub>reac</sub>) using Eqs. (1)–(6). Reactive N losses included losses of N compounds likely to negatively impact water bodies and/or the atmosphere such as NO<sub>3</sub>-N leaching, nitrous oxide N<sub>2</sub>O-N emissions, NH<sub>3</sub>-N volatilization, and surface N transport from runoff and erosion (Zellweger et al., 2003; Erisman et al., 2001; Martinelli et al., 2006).

We used Eq. (1) to calculate the NO<sub>3</sub>-N leaching ( $\Delta\text{NO}_3\text{-N}$ ), Eq. (2) for nitrous oxide N<sub>2</sub>O-N losses ( $\Delta\text{N}_2\text{O-N}$ ), Eq. (3) for NH<sub>3</sub>-N volatilization ( $\Delta\text{NH}_3\text{-N}$ ), Eq. (4) for surface N transport not connected to soil erosion ( $\Delta\text{N}_{\text{st}}$ ), Eq. (5) for surface N transport caused by soil erosion, and Eq. (6) for NTT difference in reactive N losses (NTT-DNL<sub>reac</sub>). These pathways of reactive N should be accounted for since users are interested in surface transport of N, NO<sub>3</sub>-N leaching, and atmospheric N<sub>2</sub>O-N losses (Gross et al., 2008; Mosier et al., 1996) as well as emissions of NH<sub>3</sub>-N.

$$\Delta\text{NO}_3\text{-N} = \text{NO}_3\text{-N}_{\text{bms}} - \text{NO}_3\text{-N}_{\text{nms}} \quad (1)$$

$$\Delta\text{N}_2\text{O-N} = \text{N}_2\text{O-N}_{\text{bms}} - \text{N}_2\text{O-N}_{\text{nms}} \quad (2)$$

$$\Delta\text{NH}_3\text{-N} = \text{NH}_3\text{-N}_{\text{bms}} - \text{NH}_3\text{-N}_{\text{nms}} \quad (3)$$

$$\Delta\text{N}_{\text{st-N}} = \text{N}_{\text{st-N}}_{\text{bms}} - \text{N}_{\text{st-N}}_{\text{nms}} \quad (4)$$

$$\Delta\text{N}_{\text{er}} = \text{N}_{\text{er-N}}_{\text{bms}} - \text{N}_{\text{er-N}}_{\text{nms}} \quad (5)$$

$$\text{NTT-DNL}_{\text{reac}} = \Delta\text{NO}_3\text{-N} + \Delta\text{N}_2\text{O-N} + \Delta\text{NH}_3\text{-N} + \Delta\text{N}_{\text{st}} + \Delta\text{N}_{\text{er}} \quad (6)$$

Although, N<sub>2</sub>O-N is a trace gas, it has a significant global warming potential (GWP) and should be included as part of the reactive N. The 100-year average GWP of N<sub>2</sub>O-N is about 300 times greater than an equal mass of carbon dioxide (CO<sub>2</sub>) (Prather et al., 2001). A reduction in 1 kg N<sub>2</sub>O-N ha<sup>-1</sup> year<sup>-1</sup> could be equivalent in GWP to about 300 kg CO<sub>2</sub> ha<sup>-1</sup> year<sup>-1</sup>. We suggest that there may be potential interest for future credits of N<sub>2</sub>O-N equivalents to C sequestration and that C sequestration credits may be given for  $\Delta\text{N}_2\text{O-N}$ .

For users interested in the total N losses in the system, we used Eq. (6) to calculate N<sub>2</sub>-N denitrification ( $\Delta\text{N}_2\text{-N}$ ) and Eq. (7) to calculate the NTT difference in total N losses (NTT-DNL<sub>tot</sub>). For Eqs. (1)–(6), bms refers to the base management scenario and nms refers to the new management scenario. Users that are interested in trading reactive N will be interested in NTT-DNL<sub>reac</sub>. However, nutrient managers may be interested in the total N losses to the environment, including those from denitrification (NTT-DNL<sub>tot</sub>).

$$\Delta\text{N}_2\text{-N} = \text{N}_2\text{-N}_{\text{bms}} - \text{N}_2\text{-N}_{\text{nms}} \quad (7)$$

$$\text{NTT-DNL}_{\text{tot}} = \text{NTT-DNL}_{\text{reac}} + \Delta\text{N}_2\text{-N} \quad (8)$$

The NTT-DNL<sub>reac</sub> can be used to identify the best scenario that shows the greatest potential to maximize field-level savings in reactive N for environmental conservation and potential N credits to trade (Eq. (6)). A positive NTT-DNL<sub>reac</sub> means that the new N management practice increases the savings in reactive N with potential to trade these savings in reactive N. A negative number will mean that there is no savings in reactive N or no N available to trade. In other words, the NTT-DNL<sub>reac</sub> (Eq. (6)) can be seen as a bank account balance. A positive number means that there is money in the bank to trade, while a negative number means that there is no money in the bank to trade.

There is also opportunity to implement best management practices that increase the savings in reactive N by reducing the off-site N transport at the field level. Practices such as use of buffers and/or riparian zones, drainage management, management of tiles, and others can be implemented as practices that increase savings in reactive N at the farm. In addition, the routing of N through aquifer systems with significant lag times needs to be considered before upstream N transport is calculated for a downstream project (Follett and Delgado, 2002). For this manuscript, we will focus on assessing N losses at the field level, leaving other considerations such as N transport for future papers.

## 2. Materials and methods

### 2.1. Sites and best management scenarios

We selected three general management scenarios from diverse regions of the US. Typical no-till systems from the humid North Atlantic region (Virginia), manure operations from the Midwestern US region (Ohio), and irrigated systems from the dry Western US region (Colorado) were evaluated (Table 1). We collected information from these regions and developed average scenarios that were representative of local practices following a simulated approach as described by Shaffer and Delgado (2001). We focused on evaluating the reduced N losses on two different soil texture levels (finer and coarser) for each of these sites.

Details of the management scenarios tested at each site are described in Table 1. In the Virginia site, we tested the model with no-tillage rotations: (1) corn-corn (C); (2) corn-soybean (CS); (3) corn-winter wheat (CW); (4) corn-winter wheat-soybean (CWS); (5) corn-winter wheat-soybean-winter wheat-soybean (CWSWS). For each one of these rotations, we developed three levels of inorganic N fertilizer inputs. The high (H), medium (M), and low (L) N rates were evaluated using N inputs of 224, 202 and 146 kg N ha<sup>-1</sup> for corn, respectively, and 134, 101 and 67 kg N ha<sup>-1</sup> for winter wheat, respectively. Fertilizer N was applied at pre-planting and sidedress for corn. For winter wheat, N fertilizer was split into pre-planting and spring applications. Soybeans were not fertilized.

In Ohio, we tested several manure management scenarios such as manure surface applied double rate (fall and spring applied, MSDR), manure surface applied reduced rate (spring applied, MSRR), manure injected (spring applied, MI), manure surface applied split application (spring applied, MSS),

**Table 1 – Selected sites from the North Atlantic region (Virginia), Midwest region (Ohio) and dry, irrigated Western region (Colorado) of the United States**

MS <sup>a</sup>	State	Texture <sup>b</sup>	Nitrogen input		
kg N ha <sup>-1</sup>					
BB	CO	SL & LS	High (134–134)	Medium (112–112)	Low (67–67)
PBB	CO	SL & LS	High (280–134–134)	Medium (235–112–112)	Low (190–67–67)
PB	CO	SL & LS	High (280–134)	Medium (235–202)	Low (190–67)
PPB	CO	SL & LS	High (280–280–134)	Medium (235–235–112)	Low (190–190–67)
PP	CO	SL & LS	High (280–280)	Medium (235–235)	Low (190–190)
Mg ha <sup>-1</sup>					
MSDR	OH <sup>c</sup>	L & SL	220 liquid & 29 solid fall surface applied and 220 liquid and 29 solid spring surface applied		
MI	OH	L & SL	220 liquid and 29 solid spring surface applied		
MS	OH	L & SL	54, 54, 54, and 54 liquid, and 29 solid spring surface applied		
MSS	OH	L & SL	220 liquid and 29 solid spring surface applied		
MSRR	OH	L & SL	149 liquid and 20 solid spring surface applied		
kg N ha <sup>-1</sup>					
C	VA	SL & LS	High (224–224)	Medium (202–202)	Low (146–146)
CS	VA	SL & LS	High (224–0)	Medium (202–0)	Low (146–0)
CW	VA	SL & LS	High (224–134)	Medium (202–101)	Low (146–67)
CWS	VA	SL & LS	High (224–134–0)	Medium (202–101–0)	Low (146–67–0)
CWSWS	VA	SL & LS	High (224–134–0–134–0)	Medium (202–101–0–101–0)	Low (146–67–0–67–0)

<sup>a</sup> MS, Management scenario; C, corn; S, soybean; WW, winter wheat; MSDR, manure surface double rate (applied fall and spring); MI, manure injected (spring applied); MS, manure surface (spring applied); MSS, manure surface split applications (spring applied); MSRR, manure surface reduced rate (spring applied); B, barley; P, potato.

<sup>b</sup> SL, Sandy loam; LS, loamy sand; L, loam.

<sup>c</sup> The crop rotation in Ohio was corn–soybean. Manure was applied only in spring before corn planting. For the double rate, the manure was applied in spring before corn planting and fall after soybean harvesting.

and manure surface applied (spring applied, MS). The rates of solid and liquid applications are described in Table 1. In Colorado, we tested the combination of shallower (potato) and deeper rooted (malting barley) crop rotations in irrigated systems. The high, medium, and low N rates were 280, 235 and 190 kg N ha<sup>-1</sup> year<sup>-1</sup>, respectively for potato; and 134, 112 and 67 kg N ha<sup>-1</sup> year<sup>-1</sup>, respectively, for malting barley. Potato was fertilized at planting and during the growing season with fertigation. Fertilizer N was applied at pre-planting for barley.

## 2.2. Time frame (24 years)

For a modeling approach to evaluate the effect of management scenarios on reduced N losses, we suggest a time period that consists of 12 years of sequential model initialization and 12 years of sequential model evaluation. This allows for full comparisons of cropping system combinations that are grouped in multiples of 1, 2, 3, or 4 years after the effects of initial conditions have been removed. There may be cases where initial conditions need to be included, and this can be done as is appropriate. The 12-year scheme allows the comparison of those sites and rotations using similar time frame combinations across a time rotation cycle.

The NLEAP model allows for more than one crop per year. For example, the CWS rotation in Virginia is three crops in 2 years, however, by using a time frame of 12 years, we can evaluate cropping cycles for C, CS, CWS, and CWSWS by using the same weather pattern available at the site. If users are interested in using a larger time frame, the model is flexible enough to allow this. However, our manuscript is based on a 24-year time frame evaluation.

## 2.3. Soil and weather databases and assessments of long-term effects on NTT-DNL<sub>reac</sub>

We used the USDA-NRCS SURRGO soil and weather databases that were downloaded from the NRCS web site (Shaffer et al., in press). The new NLEAP-GIS software converted the soil and weather databases to the NLEAP-GIS format. The simulation period used for all of these sites was from January 1, 1974 to January 31, 1997. Traditional management data were collected by contacting personnel from the NRCS, Universities, and/or the ARS at these sites. Each management scenario described in Table 1 was run sequentially from 1974 to 1997.

NLEAP-GIS does not account for N losses due to surface soil erosion (sediment transport). These effects can be assessed with the RUSLE 2 model (Renard and Ferreira, 1993; Renard et al., 1991; Wischmeier and Smith, 1965, 1978). For this exercise, losses of N due to off-site sediment transport were not included. In the majority of our selected scenarios, the erosion potential was minimal. The Virginia sites were no-till, and the Ohio sites were no-till forage corn.

The irrigated Colorado site has sandy soils with high infiltration rates and low surface erosion potential. The Colorado soils had slopes lower than 2%. However, we acknowledge that for the Colorado PP rotation with conventional tillage, the wind erosion will be significant. Refer to Al-Sheikh et al. (2005) for impacts of crop rotations on N pools. This erosion will be especially high and can remove significant amounts of N tied up with the recalcitrant N pool for a PP rotation (Al-Sheikh et al., 2005).

Since we intensively studied these rotations and were specifically looking at the effects of management scenarios on the NTT-DNL<sub>reac</sub>, we suggest that this is still a valid approach

**Table 2 – Assessment of Nitrogen Trading Tool annual difference in total nitrogen losses (NTT-DNL<sub>tot</sub>) and Nitrogen Trading Tool difference in reactive nitrogen losses (NTT-DNL<sub>reac</sub>) at the field level for management scenarios<sup>a,b</sup> for two types of Colorado soils**

	NTT-DNL <sub>tot</sub>		NTT-DNL <sub>reac</sub>	
	Gu (kgN ha <sup>-1</sup> )	MG (kgN ha <sup>-1</sup> )	Gu (kgN ha <sup>-1</sup> )	MG (kgN ha <sup>-1</sup> )
PPH-BBH	85	82	85	82
PPH-PBBH	58	56	58	56
PPH-PBH	45	42	45	42
PPH-PPBH	29	28	29	28
PPH-PPM	32	40	32	40
PPH-BBM	88	95	88	95
PPH-PBBM	65	80	65	80
PPH-PBM	63	74	63	74
PPH-PPBM	51	62	51	62
PPH-PPL	58	70	58	70
PPH-BBL	93	98	93	98
PPH-PBBL	81	91	81	91
PPH-PBL	77	90	77	90
PPH-PPBL	69	84	69	84

Soil types were Gunbarrel loamy sand (Gu) and McGinty sandy loam (MG).

<sup>a</sup> B, Barley; P, potato, H, high N input; M, medium N input; L, low N input.

<sup>b</sup> The base management scenario (BMS) is continuous potato–potato high N inputs (PPH).

to evaluate the effect of management scenarios on NTT-DNL<sub>reac</sub>. Additionally, we recommend that for cases where erosion can be a problem, the N losses due to erosion ( $\Delta N_{er}$ ) need to be assessed with the RUSLE 2 model for surface erosion or with the wind erosion model for aerial erosion that may be dominant in dry regions (Bondy et al., 1980; Skidmore et al., 1970; USDA-SCS, 1988; Woodruff and Siddoway, 1965).

#### 2.4. Parameters and information used in the NLEAP-GIS NTT

The examples that were used to run the NLEAP model for this paper will be available as part of the software package (Delgado and Shaffer, in press). Users will have access to the new NLEAP-GIS model, with examples from typical no-till systems in the humid North Atlantic region (Virginia), manure operations in the Midwestern US region (Ohio), and irrigated systems in the dry Western US region (Colorado) (Table 1). The soil and weather databases and assessments will be available as examples with the NLEAP-GIS Training Manual.

### 3. Results and discussion

#### 3.1. Assessment of NTT-DNL<sub>reac</sub> at the field level—Colorado

The base management scenario for Colorado is the continuous potato–potato rotation with high N inputs (PPH; Table 2). The management scenario most susceptible to N losses was the PPH (mainly due to NO<sub>3</sub>-N leaching; Tables 2 and 3). Since the N losses due to denitrification were minimal in these sandy coarse soils the NTT-DNL<sub>reac</sub> and NTT-DNL<sub>tot</sub> were similar and the main pathway for N losses was NO<sub>3</sub>-N leaching (Tables 2 and 3).

The NTT-DNL<sub>reac</sub> ranged was 88–98 kgN ha<sup>-1</sup> when PPH was compared to the continuous barley–barley rotation with medium (BBM) or low (BBL) N inputs (Table 2). If the nutrient manager changes from the base management scenario (PPH) to PPL, he/she could receive a NTT-DNL<sub>reac</sub> of 58 and 70 kgN ha<sup>-1</sup> year<sup>-1</sup> for Gunbarrel and McGinty soils, respectively (Table 2). This agrees with Meisinger and Delgado (2002) and Delgado and Bausch (2005) who reported that with closer synchronization of N inputs to crop N sinks, we can increase N use efficiencies while reducing N losses to the environment.

Comparisons between each modified management scenario and the corresponding baselines are presented in Table 3. We can assess the benefits of using better N fertilizer applications that match N uptake at a medium N application, as well as the benefits of rotations with deeper rooted crops such as malting barley that can serve as a vertical filter strip to recover (mining nitrates) NO<sub>3</sub>-N from groundwater (Delgado, 1998, 2001; Delgado et al., 2001a,b).

#### 3.2. Assessment of NTT-DNL<sub>reac</sub> at the field level—Ohio

The baseline management scenario for Ohio was the manure surface double rate (fall and spring applied, MSDR; Table 4). Denitrification losses for Ohio Haskin sandy loam and Fulton loam were significant (Table 5). The denitrification N losses ranged from 24% to 40% of total N losses on the Haskin sandy loam, and 44% to 58% on the Fulton loam (Table 5). In other words, after implementation of best N management practices the losses of reactive N were 34–44% lower for the loam and 13–18% lower for the sandy loam than the total N losses, including denitrification (Table 4).

This data suggest that the heavier fine soils under no-till systems with high denitrification potential are those areas

**Table 3 – Effects of management scenarios on annual-term N loss averages for nitrate ( $\text{NO}_3\text{-N}$ ) leaching loss (NL), denitrification ( $\text{N}_2\text{-N}$ ) (Den), trace gas emissions of nitrous oxide ( $\text{N}_2\text{O-N}$ ) (TG), surface runoff (Runoff), and ammonia volatilization ( $\text{NH}_3\text{-N}$ ) in relation to total N losses (TNL), reactive nitrogen losses (RNL), and residual soil nitrate ( $\text{NO}_3\text{-N}$ ) (RSN) in the soil profile, and soil type (ST) in Colorado**

Management scenario	NL ( $\text{kg N ha}^{-1}$ )	Den ( $\text{kg N ha}^{-1}$ )	TG ( $\text{kg N ha}^{-1}$ )	Runoff ( $\text{kg N ha}^{-1}$ )	$\text{NH}_3\text{-N}$ ( $\text{kg N ha}^{-1}$ )	TNL ( $\text{kg N ha}^{-1}$ )	RNL ( $\text{kg N ha}^{-1}$ )	RSN ( $\text{kg N ha}^{-1}$ )	ST ( $\text{kg N ha}^{-1}$ )
<b>High N inputs</b>									
BB	16	0	1	0	0	17	17	13	Gu
PBB	43	0	1	0	0	44	44	17	Gu
PB	56	0	1	0	0	57	57	27	Gu
PPB	72	0	1	0	0	73	73	27	Gu
PP	101	0	1	0	0	102	102	36	Gu
BB	18	0	1	0	0	19	19	93	MG
PBB	43	0	1	0	0	45	45	154	MG
PB	57	0	1	0	0	59	59	170	MG
PPB	72	0	2	0	0	73	73	167	MG
PP	100	0	2	0	0	101	101	197	MG
<b>Medium N inputs</b>									
BB	13	0	0	0	0	14	14	13	Gu
PBB	36	0	1	0	0	37	37	16	Gu
PB	38	0	1	0	0	39	39	12	Gu
PPB	50	0	1	0	0	51	51	14	Gu
PP	69	0	1	0	0	70	70	28	Gu
BB	5	0	1	0	0	6	6	26	MG
PBB	20	0	1	0	0	21	21	72	MG
PB	26	0	1	0	0	27	27	89	MG
PPB	37	0	1	0	0	39	39	100	MG
PP	60	0	2	0	0	61	61	129	MG
<b>Low N inputs</b>									
BB	8	0	0	0	0	9	9	12	Gu
PBB	21	0	1	0	0	21	21	15	Gu
PB	24	0	1	0	0	25	25	11	Gu
PPB	32	0	1	0	0	33	33	12	Gu
PP	43	0	1	0	0	44	44	20	Gu
BB	3	0	1	0	0	3	3	15	MG
PBB	9	0	1	0	0	10	10	21	MG
PB	10	0	1	0	0	11	11	21	MG
PPB	16	0	1	0	0	17	17	26	MG
PP	29	0	1	0	0	31	31	61	MG

Soil types were Gunbarrel loamy sand (Gu) and McGinty sandy loam (MG). B, Barley and P, potato (background nitrate in irrigation water was about  $40 \text{ kg N ha}^{-1} \text{ year}^{-1}$ ).

**Table 4 – Assessment of Nitrogen Trading Tool annual difference in total nitrogen losses ( $\text{NTT-DNL}_{\text{tot}}$ ) and Nitrogen Trading Tool difference in reactive nitrogen losses ( $\text{NTT-DNL}_{\text{reac}}$ ) at the field level for management scenarios<sup>a,b</sup> for two types of Ohio soils**

	$\text{NTT-DNL}_{\text{tot}}$		$\text{NTT-DNL}_{\text{reac}}$	
	Ha ( $\text{kg N ha}^{-1}$ )	Fu ( $\text{kg N ha}^{-1}$ )	Ha ( $\text{kg N ha}^{-1}$ )	Fu ( $\text{kg N ha}^{-1}$ )
MSDR-MSRR	191	176	156	102
MSDR-MI	160	150	139	99
MSDR-MSS	153	142	126	80
MSDR-MS	157	146	132	87

Soil types were Haskin sandy loam (Ha) and Fulton loam (Fu).

<sup>a</sup> MSDR, Manure surface double rate (applied fall and spring); MSRR, manure surface reduced rate (spring applied); MI, manure injected (spring applied); MSS, manure surface split applications (spring applied); MS, manure surface (spring applied).

<sup>b</sup> The base management scenario is manure surface double rate (applied fall and spring) (MSDR).

**Table 5 – Effects of management scenarios on annual-term annual N loss averages for nitrate ( $\text{NO}_3\text{-N}$ ) leaching loss (NL), denitrification ( $\text{N}_2\text{-N}$ ) (Den), trace gas emissions of nitrous oxide ( $\text{N}_2\text{O-N}$ ) (TG), surface runoff (Runoff), and ammonia volatilization ( $\text{NH}_3\text{-N}$ ) in relation to total N losses (TNL), reactive nitrogen losses (RNL), and residual soil nitrate ( $\text{NO}_3\text{-N}$ ) (RSN) in the soil profile, and soil type (ST) in Ohio**

Manure treatment <sup>a</sup>	NL ( $\text{kg N ha}^{-1}$ )	Den ( $\text{kg N ha}^{-1}$ )	TG ( $\text{kg N ha}^{-1}$ )	Runoff ( $\text{kg N ha}^{-1}$ )	$\text{NH}_3\text{-N}$ ( $\text{kg N ha}^{-1}$ )	TNL ( $\text{kg N ha}^{-1}$ )	RNL ( $\text{kg N ha}^{-1}$ )	RSN ( $\text{kg N ha}^{-1}$ )	ST ( $\text{kg N ha}^{-1}$ )
MSRR	22	31	5	0	25	83	52	41	Ha
MI	44	45	6	0	19	114	69	47	Ha
MSS	32	39	5	0	44	121	82	42	Ha
MSDR	131	66	8	0	68	274	208	264	Ha
MS	36	41	6	0	34	117	76	43	Ha
MSRR	13	38	4	0	25	80	42	30	Fu
MI	21	61	6	0	18	106	45	30	Fu
MSS	16	50	5	0	43	114	64	30	Fu
MSDR	66	112	10	0	67	256	144	85	Fu
MS	17	53	6	0	34	110	57	30	Fu

Soil types were Haskin sandy loam (Ha) and Fulton loam (Fu).

<sup>a</sup> MSRR, manure surface reduced rate (spring applied); MI, manure injected (spring applied); MSS, manure surface split applications (spring applied); MS, manure surface (spring applied); MSDR, Manure surface double rate (applied fall and spring).

better suited to mitigation of N losses to the environment, as long as the denitrification potential is high. These heavier fine soils under no-till systems will have a lower NTT-DNL<sub>reac</sub> when compared to the coarser sandy soils. The no-till areas with higher potential for N trading are the heavy coarse soils with low denitrification potential. These no-till sites could have a higher NTT-DNL<sub>reac</sub> and higher potential for N credit trading (Tables 4 and 5).

To reduce N losses from these sensitive areas with higher NTT-DNL<sub>reac</sub>, nutrient managers could use the principles from Meisinger and Delgado (2002) to maximize N credits. The use of controlled release fertilizers can mitigate N losses from these sensitive areas (Delgado and Mosier, 1996).

Although our paper is focused on assessment of N losses at the field level, leaving other considerations such as N transport outside of the field for future papers, we suggest that distances to water bodies is important and must be considered in future papers. Delgado et al. (2006, 2008) developed an N index factoring the distance from the field to water bodies and aquifers. A similar system may be applied to the trading of N, especially for areas with high NTT-DNL<sub>reac</sub> close to water bodies.

The NTT-DNL<sub>reac</sub> shows that the management scenario resulting in the greatest N losses is the double manure rates (fall and spring) (Table 4). A nutrient manager could effect an average of  $156 \text{ kg N ha}^{-1} \text{ year}^{-1}$  for NTT-DNL<sub>reac</sub> on a Haskin soil if he/she does not apply manure in the fall period and only applies manure in the spring. The data suggest that there are additional benefits from incorporating the manure and from reducing the spring application rates (Table 5).

From the manure case scenario in Ohio, we can see reductions in the emissions of nitrous oxide ( $\text{N}_2\text{O-N}$ ) (Table 5). Anthropogenic emissions of this trace gas have been reported to increase atmospheric concentrations that have potential impacts on global warming (IPCC, 1996). Management of N inputs through use of appropriate type of N, nitrification inhibitors, and/or controlled release fertilizers can reduce  $\text{N}_2\text{O-N}$  emissions (Bronson and Mosier, 1993; Delgado and Mosier, 1996; Minami, 1992).

The Ohio example shows the potential for improvement in manure management. A nutrient manager will receive a  $\Delta \text{N}_2\text{O-N}$  of  $3\text{--}6 \text{ kg N ha}^{-1}$  by reducing the manure rate or a  $\Delta \text{N}_2\text{O-N}$  of three to five by splitting applications or by applying only in the spring when compared to the double rate manure applications (Table 5). This could be equivalent in GWP to savings of about  $900\text{--}1800 \text{ kg CO}_2 \text{ ha}^{-1} \text{ year}^{-1}$ .

### 3.3. Assessment of NTT-DNL<sub>reac</sub> at the field level—Virginia

The baseline management scenario for Virginia is the continuous conventional corn-corn rotation with high N inputs (CH; Table 6). Since the N losses due to denitrification were minimal in the Bojac loamy sand soil, the NTT-DNL<sub>reac</sub> and NTT-DNL<sub>tot</sub> were similar (Table 6). Denitrification N losses for Virginia Tetotum loam were significant (Table 7). Denitrification N losses ranged from 30% to 36%, 30% to 36%, and 32% to 40% of total N losses for the high, medium, and low N inputs, respectively. Although the percentage of the N losses due to denitrification increased with reduction of N inputs in

**Table 6 – Assessment of Nitrogen Trading Tool annual difference in total nitrogen losses (NTT-DNL<sub>tot</sub>) and Nitrogen Trading Tool difference in reactive nitrogen losses (NTT-DNL<sub>reac</sub>) at the field level for management scenarios<sup>a,b</sup> for two types of Virginia soils**

	NTT-DNL <sub>tot</sub>		NTT-DNL <sub>reac</sub>	
	Te (kg N ha <sup>-1</sup> )	Bj (kg N ha <sup>-1</sup> )	Te (kg N ha <sup>-1</sup> )	Bj (kg N ha <sup>-1</sup> )
CH-CSH	37	36	26	36
CH-CWH	1	0	–3	0
CH-CWSH	1	6	–12	6
CH-CWSWSH	0	6	–19	6
CH-CM	20	20	8	20
CH-CSM	47	46	27	46
CH-CWM	27	25	27	25
CH-CWSM	25	28	1	28
CH-CWSWSM	24	28	–4	28
CH-CL	71	69	38	69
CH-CSL	75	71	34	71
CH-CWL	67	65	26	65
CH-CWSL	64	64	23	64
CH-CWSWSL	59	59	15	59

Soil types were Bojac loamy sand (Bj) and Tetotum loam (Te).

<sup>a</sup> C, Corn; S, soybean; W, winter wheat; H, high N input; M, medium N input; L, low N input.

<sup>b</sup> The base management scenario is continuous corn high N input (CH).

the Tetotum loam, the total magnitude of the denitrification N losses reduced by 50% from averages of 18 and 36 kg N<sub>2</sub>-N ha<sup>-1</sup> year<sup>-1</sup> for the low and high N inputs, respectively.

Similarly, in Ohio, the data show that the fine soils under no-till systems have higher denitrification potential. The Ohio NTT-DNL<sub>reac</sub> for the finer soil is lower than those from coarser soils (Table 4). The Ohio Bojac loamy sand soil NTT-DNL<sub>reac</sub> with low N inputs ranged from 59 to 71 kg N ha<sup>-1</sup> year<sup>-1</sup>; higher than the 15 to 38 kg N ha<sup>-1</sup> year<sup>-1</sup> for the Tetotum loam (Table 6).

For the no-till Virginia systems, there were savings in reactive N at the high N inputs by switching from the continuous corn baseline scenario to a corn-soybean rotation (Table 7). The NTT-DNL<sub>reac</sub> was 26 and 36 kg N ha<sup>-1</sup> year<sup>-1</sup> for the Tetotum loam and Bojac loamy sand, respectively (Table 6). This is in agreement with the principles presented by Meisinger and Delgado (2002) to reduce NO<sub>3</sub>-N leaching. Adding a small grain into the corn-soybean rotation will generate an NTT-DNL<sub>reac</sub> increase of 23–64 kg N ha<sup>-1</sup> year<sup>-1</sup> with the low N input scenario. These examples show that a nutrient manager could receive a delta N<sub>2</sub>O-N of 2 to 4 kg N ha<sup>-1</sup> year<sup>-1</sup> by reducing the N rate and adding a leguminous crop (Table 7). This could be equivalent in GWP to savings of about 600–1200 kg CO<sub>2</sub> ha<sup>-1</sup> year<sup>-1</sup>.

The N<sub>2</sub>O-N emission losses across soils in Virginia were slightly higher for the loam than for the loamy sand. As with all other states, the reduction of N inputs will cut N losses (Table 7).

### 3.4. Nitrogen losses and residual soil NO<sub>3</sub>-N—Colorado

The NO<sub>3</sub>-N leaching is higher for the shallower potato systems than the deeper rooted barley system (Table 3). The

residual soil NO<sub>3</sub>-N is much higher for the potato system than the small grain barley system (Table 3). These results are in agreement with previous NLEAP calibration/validation efforts for this region (Delgado, 1998, 2001; Delgado et al., 2001a,b). Small grains serve as scavenger crops and reduce NO<sub>3</sub>-N leaching. Additionally, the residual soil NO<sub>3</sub>-N for the potato systems was higher for the sandy loams than the residual soil NO<sub>3</sub>-N observed for the loamy sands (Table 3), which is in agreement with previous calibration/validation efforts.

The deeper rooted crops serve as vertical filter strips to mine and recover NO<sub>3</sub>-N from underground water. Intensive rotations with higher N inputs and shallower rooted systems will increase the N losses. However, adequate rotations with deeper rooted crops will reduce N losses by providing a vertical filter strip (Delgado, 1998, 2001; Delgado et al., 2001a,b). There is potential to improve synchronization of N inputs with applications and to credit other N sources such as residual soil NO<sub>3</sub>-N in irrigated background waters for this region (Ristau, 1999; Delgado, 2001).

### 3.5. Nitrogen losses and residual soil NO<sub>3</sub>-N—Ohio

In Ohio, manure applications (double rate) applied in the fall and spring caused more NO<sub>3</sub>-N leaching than the spring manure applications at half rate (Table 5). Reducing manure N applications in the spring significantly reduced NO<sub>3</sub>-N leaching. The average NO<sub>3</sub>-N leaching losses in Ohio were lower than those from the irrigated, shallower rooted crops in Colorado, however, the losses are higher than those observed in the irrigated small grain rotations of Colorado.

Results of NO<sub>3</sub>-N leaching in Ohio shown in Table 5 are in accordance with the findings of Kirchmann and Bergstrom

**Table 7 – Effects of management scenarios on annual-term N loss averages for nitrate (NO<sub>3</sub>-N) leaching loss (NL), denitrification (N<sub>2</sub>-N) (Den), trace gas emissions of nitrous oxide (N<sub>2</sub>O-N) (TG), surface runoff (runoff), and ammonia volatilization (NH<sub>3</sub>-N) in relation to total N losses (TNL), reactive nitrogen losses (RNL), and residual soil nitrate (NO<sub>3</sub>-N) (RSN) in the soil profile, and soil type (ST) in Virginia**

Management scenario	NL (kg N ha <sup>-1</sup> )	Den (kg N ha <sup>-1</sup> )	TG (kg N ha <sup>-1</sup> )	Runoff (kg N ha <sup>-1</sup> )	NH <sub>3</sub> -N (kg N ha <sup>-1</sup> )	TNL (kg N ha <sup>-1</sup> )	RNL (kg N ha <sup>-1</sup> )	RSN (kg N ha <sup>-1</sup> )	ST (kg N ha <sup>-1</sup> )
High N inputs									
C	97	0	4	0	1	103	103	152	Bj
CS	62	0	3	0	1	67	67	80	Bj
CW	95	0	2	1	4	103	103	132	Bj
CWS	89	0	3	1	4	97	97	134	Bj
CWSWS	88	0	3	1	6	97	97	134	Bj
C	66	43	8	0	1	118	54	97	Te
CS	46	28	6	0	1	81	28	56	Te
CW	71	35	6	1	4	117	57	92	Te
CWS	69	37	6	1	4	117	66	103	Te
CWSWS	71	35	6	1	6	118	73	108	Te
Medium N inputs									
C	78	0	4	0	1	83	83	122	Bj
CS	53	0	3	0	1	57	57	71	Bj
CW	72	0	2	1	3	78	78	102	Bj
CWS	69	0	2	1	3	75	75	107	Bj
CWSWS	68	0	2	0	4	75	75	106	Bj
C	54	35	7	0	1	98	46	81	Te
CS	39	24	6	0	1	71	27	51	Te
CW	55	28	5	1	3	91	27	55	Te
CWS	55	30	5	1	3	93	53	83	Te
CWSWS	55	28	5	1	4	94	58	86	Te
Low N inputs									
C	29	0	4	0	1	34	34	44	Bj
CS	28	0	3	0	1	32	32	48	Bj
CW	34	0	2	1	2	38	38	58	Bj
CWS	34	0	2	1	2	39	39	63	Bj
CWSWS	39	0	2	0	3	44	44	70	Bj
C	20	19	6	0	1	47	16	35	Te
CS	21	16	5	0	1	43	20	36	Te
CW	27	18	4	1	2	51	28	46	Te
CWS	28	19	4	1	2	54	31	50	Te
CWSWS	32	19	4	1	3	59	39	58	Te

Soil types were Bojac loamy sand (Bj) and Tetotum loam (Te). C, Corn; S, soybean; W, winter wheat.

(2001). They reported that a reduction of  $\text{NO}_3\text{-N}$  leaching is not a question of organic versus inorganic N fertilizer inputs. The intensity of  $\text{NO}_3\text{-N}$  leaching is related to N input rates (organic or inorganic), use of practices such as cover crops that can scavenge residual soil  $\text{NO}_3\text{-N}$ , and other management scenarios (Kirchmann and Bergstrom, 2001).

The denitrification and  $\text{NH}_3\text{-N}$  volatilization losses in Ohio were much higher than those from irrigated systems in Colorado. The emissions of  $\text{N}_2\text{O-N}$  were also significantly higher, and we suggest that these were driven by the larger denitrification losses. The incorporation of manure significantly reduced the  $\text{NH}_3\text{-N}$  losses to the environment. The average residual soil  $\text{NO}_3\text{-N}$  for these manure systems was low. The total N losses for these manure sites were higher than those observed in the irrigated vegetable and small grain rotations.

### 3.6. Nitrogen losses and residual soil $\text{NO}_3\text{-N}$ —Virginia

In Virginia, the corn–soybean (CS) rotation significantly contributed to the reduction of  $\text{NO}_3\text{-N}$  leaching losses when compared to other rotations (Table 7). This is in agreement with the principles of managing N to reduce  $\text{NO}_3\text{-N}$  leaching losses described by Meisinger and Delgado (2002). The  $\text{NO}_3\text{-N}$  leaching losses were significantly reduced with reduction of N inputs. The  $\text{NO}_3\text{-N}$  leaching losses were higher for the Bojac loamy sand than those of the Tetotum loam. This is in agreement with Delgado et al. (2001a) and Delgado (2001).

The denitrification for the coarse, sandy soils was minimal, but the  $\text{N}_2\text{O-N}$  losses in the loam soil were higher in Virginia and contributed to significant overall N losses. The  $\text{NH}_3\text{-N}$  volatilization for these Virginia soils was low. Precipitation events and an acidic soil pH contribute to a reduction of the atmospheric losses due to  $\text{NH}_3\text{-N}$  volatilization of the inorganic N inputs. The residual soil  $\text{NO}_3\text{-N}$  was significantly higher than those observed in manure applications, suggesting the potential for higher  $\text{NO}_3\text{-N}$  leaching during the winter period. These sites may benefit from the incorporation of a winter cover crop after soybean to scavenge the residual soil  $\text{NO}_3\text{-N}$  (Dabney et al., 2001; Delgado, 1998).

## 4. Summary and conclusions

To help quantify management-induced reductions in N losses at the farm field level, we defined the new concept of Nitrogen Trading Tool difference in reactive N losses (NTT-DNL<sub>reac</sub>) as the comparison between the base and new management scenarios. NTT-DNL<sub>reac</sub> can be used to identify the best scenario that shows the greatest potential to maximize field-level savings in reactive N for environmental conservation and potential N credits to trade. A positive NTT-DNL<sub>reac</sub> means that the new N management practice increases the savings in reactive N with potential to trade these savings in reactive N. A negative number means that there is no savings in reactive N or no N available to trade.

The new NLEAP-GIS can be used to quickly identify the best scenario that shows the greatest potential to maximize field-

level savings in reactive N for environmental conservation and potential N credits to trade. We propose that this NTT-DNL<sub>reac</sub> approach can be used to conduct quick assessment of management practices' effects on N losses. We recommend communication and interaction between scientists and nutrient managers from the USDA-ARS, the USDA-NRCS, Universities, Extension Agencies, and others to develop a series of local, regional, and national rules about how to trade these savings in reactive N in air and water quality markets and/or  $\text{N}_2\text{O}$  equivalents to C sequestration.

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